

# Comparative Safety Analysis of Electric Wheelchairs Based on Sidewalk Width Differences

Koji Sakai, Tomoko Tonami, Hiroshi Kanaji

Kyoto Koka University 38 Kadono-cho Nishikyogoku, Kyoto, Japan

The purpose of this study was to clarify the effects of different sidewalk widths on the driving characteristics of electric wheelchairs and on the user's psychology and safety. Eighteen participants drove electric wheelchairs on both wide and narrow sidewalks. Data collection included: (1) the number of cyclists and pedestrians passing by, (2) driving speed, (3) an 11-item questionnaire, and (4) a post-test ride interview. The results showed that the number of cyclists and pedestrians they passed and their driving speed were significantly higher on wide sidewalks. On the other hand, on narrow sidewalks, negative evaluations were frequently given, including the difficulty of avoiding steps, slopes, and utility poles, anxiety and psychological tension associated with pedestrian consideration, and difficulty in operation. These results indicate that sidewalk width is not just a physical space, but also an important environmental factor that strongly influences users' anxiety, operational burden, and distance adjustment from pedestrians. Creating a safe and comfortable mobility environment requires both improvements to sidewalk infrastructure and innovations in mobility devices.

*Keywords:* electric wheelchair, WHILL, sidewalk width, safety, test drive experiment

## Introduction

With the increasing elderly population, creating an urban environment where everyone can move around safely is an urgent issue. For elderly people who have difficulty traveling the last mile, electric wheelchairs can complement their walking ability and become an important means of transportation, expanding opportunities for outings. However, multiple hurdles exist in their use. Both psychological hurdles, such as not wanting to be seen by others and the image of wheelchairs as being weak, and physical hurdles, such as the inability to overcome steps of even a few centimeters, have been identified as factors hindering their widespread use (Horide, 2023). While the development of models with improved design and maneuverability, such as the electric wheelchair WHILL (n.d.), is one solution to these challenges, environmental improvements across society as a whole are still essential.

---

**Acknowledgments:** We would like to express our gratitude to Kyoto Daihatsu Sales Co., Ltd. for their generous advice. This research was supported by the Grant-in-Aid for Scientific Research (C) "Verification of Opportunities to Go out and Improvement of QOL by Using an Electric Wheelchair in Daily Life" (Research Project 25K05636).

Koji Sakai, Ph.D., Professor, Faculty of Career Development, Kyoto Koka University 38 Kadono-cho Nishikyogoku, Ukyo-ku, Kyoto, Japan.

Tomoko Tonami, Ph.D., Associate Professor, Faculty of Health Science, Kyoto Koka University 38 Kadono-cho Nishikyogoku, Ukyo-ku, Kyoto, Japan.

Hiroshi Kanaji, Ph.D., Professor, Faculty of Career Development, Kyoto Koka University 38 Kadono-cho Nishikyogoku, Ukyo-ku, Kyoto, Japan.

Realizing an environment where everyone can move around safely requires both improvements to road infrastructure and technological development in mobility (Kondo, 2025). These include (1) infrastructure development that systematically and continuously repairs sidewalks to reduce hazards due to unevenness and aging, and (2) technological improvements to personal mobility devices that can be operated safely even in existing, inadequate infrastructure. However, (1) requires a large investment due to the wide-ranging infrastructure, while (2) inevitably leads to increased equipment costs due to higher performance. Therefore, relying solely on one approach is unrealistic; instead, a hybrid approach that appropriately combines both is required (Kondo, 2025).

Inadequacies in the road environment, particularly sidewalk width, step differences, and road surface conditions, significantly affect the operability of electric wheelchairs and the psychology of users. According to the definition of the Ministry of Land, Infrastructure, Transport and Tourism (2024), a sidewalk is the area physically separated from the roadway by curbs or other barriers, with a minimum width of 2.0 m for sidewalks and 3.0 m for bicycle and pedestrian paths. Furthermore, the minimum width for wheelchairs is approximately 1 m when passing through, making two-way traffic difficult on narrow sidewalks. Previous research (Kitagawa, Okamoto, Mihoshi, & Matsumoto, 1999) has shown that pedestrian speed decreases when wheelchairs are present on sidewalks with a width of 3.25 m, while the impact is smaller at 4.0 m. The study found that narrower roads tend to prevent pedestrians from checking ahead and avoiding obstacles without slowing down. Instead, pedestrians avoid obstacles within approximately 1 meter of passing, or follow pedestrians or wheelchairs in front, matching their speed without overtaking them.

In addition, the presence of steps and gradients dramatically increases the difficulty of driving. Previous research (Tahira & Ueno, 1997) experimentally demonstrated that the greater the gradient of the sidewalk (from 0 degrees to 9.5 degrees) and the narrower the width (from 1.8 meters to 1.1 meters), the greater the difficulty for electric wheelchairs to pass. While more than half of participants found a 1.4-meter width too narrow for passing other vehicles, other studies have reported that a 1.5-meter width was acceptable for most (Fujimoto, 2009). Furthermore, approximately 30% of electric wheelchair users reported that they “do not use sidewalks”, citing “narrow sidewalks”, “steps”, and “obstacles on the sidewalk” as the top reasons given (Mizohata, 2002). These previous studies suggest that the complex road conditions of sidewalk width, steps, slopes, and obstacles have a significant impact on the safety of electric wheelchairs and their willingness to use them.

Road surface conditions also affect walking comfort and driving safety. Asphalt pavement has been reported to cause the most vibration and discomfort, while concrete pavement causes the least vibration. Vibration not only leads to physical strain on users, such as fatigue, pain, and nausea, but also reduces maneuverability, making the handlebars more likely to slip, posing a particular risk to the elderly (Tanaka & Kameno, 2010). Research has revealed that wheelchair users collect a wide range of “travel information” before setting out, including steps, elevator locations, and surrounding road shapes, demonstrating that comprehensive environmental information that supports psychological safety is essential for travel (Arai, 2019).

As can be seen, the challenges faced by electric wheelchair users are multi-layered, ranging from sidewalk width, steps and slopes, road surface conditions, obstacle placement, and even psychological hurdles. Of these complex issues, this study focuses on narrow and uneven sidewalk environments in urban areas, with the aim of clarifying the impact that sidewalk width and road surface conditions have on electric wheelchairs, as well as the actual state of anxiety and stress experienced by users. Based on the knowledge presented in previous research,

the current state of electric wheelchair operation in urban areas and possibilities for improvement will be examined through test ride experiments on public road sidewalks.

## Method

### Experimental Period

The experiment took place in November 2025, with an average temperature of 15.1 degrees (SD: 3.67 degrees) and an average humidity of 66.2% (SD: 14.0%). The experiment was conducted under sunny or cloudy conditions, without rain.

### Experimental Participants

The participants were 18 people affiliated with our university (12 students and 6 faculty members), ranging in age from 19 to 55 years (average age: 33.6 years). All 18 participants walked in their daily lives and were healthy.

### Experimental Equipment

The electric wheelchair used in this experiment was a WHILL Model S from WHILL Corporation. Its characteristics were consistent with previous test-drive experiments (Sakai & Yasuda, 2024; Sakai, 2024). The electric wheelchair body measured 1,182 mm long, 557 mm wide, and 915 mm high. Side mirrors were installed on the electric wheelchair used in this experiment.

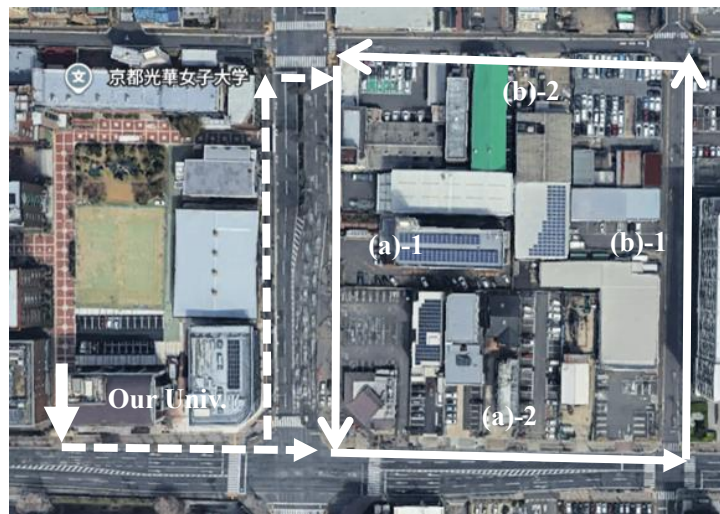


Figure 1. (a) Wide sidewalk route, (b) Narrow sidewalk route. The dotted line shows the route to the test drive route.

Table 1

*Width of Wide and Narrow Sidewalks*

Sidewalk	Width
Wide	(a)-1: 268 cm (a)-2: 367 cm
Narrow	(b)-1: 174 cm (b)-2: 168 cm

### Experimental Environment

Figure 1 shows the sidewalk routes used in the test drive experiment. (a) is a wide sidewalk route from (a)-1 to (a)-2, and (b) is a narrow sidewalk from route (b)-1 to (b)-2. Google Earth maps show route (a) as approximately 263.0 m, and route (b) as approximately 301.5 m. As shown in Figure 1, the test drive experiment

route was trapezoidal rather than a perfect rectangular grid, and the narrow sidewalk was approximately 38.5 m longer than the wide sidewalk. Table 1 shows the width of the sidewalks in Figure 1, measured by the experimenter with a tape measure.

Figure 2 shows (a) a wide sidewalk on the left and (b) a narrow sidewalk on the right. The sidewalks in both conditions were separated from the roadway by curbs or protective barriers. The sidewalks in both conditions were flat, not sloped, with several steps, inclines, and unevenness.



Figure 2. (a) Left: Wide sidewalk, (b) Right: Narrow sidewalk.

### Measurement Data

The following three items (a) through (c) were measured under two sidewalk width conditions (wide and narrow). In addition, after the sidewalk test ride experiment, the following survey data (d) was collected within our university.

(a) To measure sidewalk congestion, the experimenter used a counter to count the number of cyclists and pedestrians who passed the electric wheelchair on the sidewalk, tallying the total number of people in front and behind. People who stopped on the sidewalk, looked at their smartphones, smoked, used a cane, had a conversation with someone, or pushed a stroller or motorcycle were also counted as pedestrians. However, bicycles riding on the sidewalk from the front or pedestrians who walked onto the road and then passed the electric wheelchair were not counted.

(b) Travel speed (m/s) during the test ride was measured (travel distance (m) / travel time (s)). Under the narrow sidewalk condition, there was one crosswalk without a traffic light and one with a traffic light. If there was a waiting time, the experimenter measured it with a stopwatch and subtracted it from the electric wheelchair travel time.

(c) The electric wheelchair was stopped on the sidewalk, and the participants completed a questionnaire after each test drive under both sidewalk width conditions.

(d) After the sidewalk test drive, an interview survey was conducted with the participants on campus. During the interview survey, the experimenter asked the participants about the electric wheelchair's operability, sense of security, differences in sidewalk width, and road environment, and collected qualitative data.

### Experimental Procedure

The experimenter explained how to operate the WHILL while the participants practiced the test drive. After that, the participants practiced the test drive on a designated route within the university campus. After that, the participants moved to public roads in the electric wheelchair and test-rode on both wide and narrow sidewalks.

The participants were free to control the speed of the electric wheelchair. To ensure the participants' safety, the experimenter accompanied them by walking behind the electric wheelchair while they were test-driving. The experimenter warned participants as necessary to avoid collisions with pedestrians or cyclists during the test ride. Immediately after each test ride, participants completed a questionnaire while seated in their electric wheelchair on the sidewalk.

Eighteen participants participated in both the wide sidewalk and narrow sidewalk conditions. The order of the conditions was counterbalanced across participants. Therefore, of the 18 participants, nine participated in the order of (a) wide sidewalk to (b) narrow sidewalk conditions (Figure 1), while the other nine participated in the order of (b) narrow sidewalk to (a) wide sidewalk conditions. Immediately after the test rides on the wide sidewalk and narrow sidewalk conditions, participants rated a total of 11 items on a five-point scale. After the test rides in both conditions, participants returned to the university and conducted an indoor interview survey.

### **Ethical Considerations**

We explained in writing that the information obtained in this study would not identify individuals and that participation in the experiment was voluntary. It was explained that the risk of accidents in this test drive experiment was extremely low, and then written instructions were given that in the event of a traffic accident or other incident, the insurance to which all experiment participants had been subscribed would be applied. The experiments in this study were conducted with the approval of Kyoto Koka Women's University Research Ethics Review Board (approval number 25-1).

## **Results**

### **Number of Pedestrians and Bicycles Passing**

Table 2 compares whether there was a difference between wide and narrow sidewalks in the number of bicycles and pedestrians passing by electric wheelchairs. Results of a t-test showed that the number of bicycles and pedestrians passing by electric wheelchairs was significantly higher on wide sidewalks than on narrow sidewalks. For both bicycles and pedestrians, the number of passing bicycles and pedestrians on wide sidewalks was approximately two to three times higher. The roadway adjacent to a wide sidewalk is wider and more boulevard than the roadway adjacent to a narrow sidewalk. The number of bicycles and pedestrians in Table 2 was proportional to traffic volume.

Table 2

*Number of People Passing by Electric Wheelchairs (n = 18) Unit: Person*

Width	Bicycle	Pedestrian
Wide	4.06 (3.06)	3.89 (2.35)
Narrow	1.22 (1.48)	1.5 (1.65)
t-value	4.44***	3.1**

*Notes.* \*\*p < 0.01, \*\*\*p < 0.001, within parentheses: standard deviation.

While narrow sidewalks tend to have fewer pedestrians than wide ones, physical constraints likely lead pedestrians to slow down, making passing difficult. On narrow sidewalks, we observed cyclists and pedestrians initially riding on the sidewalk but then moving onto the open road to avoid other vehicles before passing each other. This suggests that the width of a sidewalk not only determines the amount of space available for riding, but also directly influences the probability of encountering other vehicles and their behavior.

### Powered Wheelchair Travel Speed

Table 3 shows the speed (m/s) of a powered wheelchair, calculated as the distance traveled (m) divided by the travel time (s) in seconds. The average speed of a powered wheelchair was significantly faster on wide sidewalks, at 1.36 m/s, and slower on narrow sidewalks, at 1.16 m/s. One possible explanation for this result is that wide sidewalks make it easier to avoid local obstacles such as steps, bumps, and slopes, while narrow sidewalks offer less room to maneuver around fixed objects such as utility poles, plants, and curbs. The second factor is whether or not speed is adjusted when passing bicycles or pedestrians. When a bicycle or pedestrian approaches from the front, the participants did not change the speed of their electric wheelchairs on wide sidewalks, but on narrow sidewalks they were observed to slow down or stop and give way to the bicycle or pedestrian in front. Sidewalk width is an important factor that directly affects the speed and safety of electric wheelchair users.

Table 3

*Electric Wheelchair Movement Speed (n = 18) Unit: m/s*

Width	Travel speed	t-value
Wide	1.36 (0.21)	4.73***
Narrow	1.16 (0.13)	

*Notes.* \*\*\*p < 0.001, (within parentheses): standard deviation.

### Post-Test Ride Survey Evaluation

Table 4 shows the results of the survey (five-point scale) regarding test rides on wide and narrow sidewalks. Higher values indicate more negative evaluations, such as “anxious, difficult, and undesirable”. Significant differences were observed in 9 of the 11 items, with negative evaluations being higher on narrow sidewalks.

Notable results were observed in items related to “obstacle avoidance and road surface effects”, including (1) steps and unevenness, (2) sidewalk slope, (3) collisions with side walls, and (4) collisions with utility poles and signs. All these items tended to be more negatively evaluated on narrow sidewalks, with highly significant differences observed in t-tests. This is likely due to the lack of physical space, which makes subtle maneuvers to avoid obstacles more difficult, and the increased susceptibility to slopes and uneven road surfaces that can cause steering loss.

Anxiety about contact with pedestrians and cyclists was also stronger on narrow sidewalks. This result contrasts with the results in Table 2, which showed that fewer cyclists and pedestrians passed each other on narrow sidewalks than on wide sidewalks. Although wider sidewalks tend to have more passing vehicles, narrow sidewalks offer less room for collision avoidance, suggesting that even a small number of passing vehicles can increase subjective anxiety.

Furthermore, narrow sidewalks also had higher negative ratings in operational and psychological aspects, such as (7) speed control, (9) maneuverability, (10) sense of security, and (11) overall ease of driving. This suggests that on narrow sidewalks, where the need to slow down is heightened, the combined stress of steps, slopes, and obstacles may adversely affect operational sense and reduce psychological composure. Furthermore, while there were no significant differences in (6) checking surroundings and (8) high-speed driving, the average scores were higher on narrow sidewalks, suggesting a trend toward increased attentional load on narrow sidewalks.

Overall, narrow sidewalks show a consistent tendency for power wheelchair users to be strongly influenced by external factors such as the road surface, obstacles, and pedestrians, resulting in increased difficulty in operation and feelings of anxiety. This is thought to be related not only to physical constraints but also to psychological factors such as changes in eye distribution and attention priorities when operating the wheelchair.

Table 4

*Survey Results (Higher Values Indicate More Anxiety, Difficulty, or Negative Evaluations Such as Undesirability) (n = 18, Only Item 8: n = 12)*

Question items	Wide	Narrow	t-value
1. Dealing with sidewalk steps and uneven terrain	2.44	3.28	3.07**
2. Dealing with sidewalk inclines	2.17	2.78	2.5*
3. Collisions with sidewalk walls	1.78	2.78	3.43**
4. Collisions with utility poles, trees, or signs on the sidewalk	1.61	2.78	4.74***
5. Collisions with pedestrians or cyclists	2.28	3.11	2.73*
6. Checking your surroundings	1.61	2.00	1.69
7. Speed adjustment	1.33	2.00	2.92**
8. Driving at speeds of 6km/h or more	2.50	3.17	1.88
9. Maneuverability	1.61	2.22	2.83*
10. Safety	1.89	2.33	3.06**
11. Overall ease of driving	1.61	2.17	2.75*

Notes. \*p < 0.05, \*\*p < 0.01, \*\*\*p < 0.001, (within parentheses): standard deviation.

### Interview Survey After Test Ride

Table 5 categorizes the interviews with 18 test riders and summarizes the number of respondents for each subcategory. The most frequently cited issue was “the impact of sidewalk width”, with anxiety on narrow sidewalks (15 respondents) being particularly prevalent. This result is consistent with the survey results in Table 4, in which many items related to narrow sidewalks were negatively evaluated, suggesting that sidewalk width has a strong impact on the psychological stress of using a power wheelchair.

The next most common issue was “steps, road surface, and vibration”, with many issues related to stability during riding cited, including shaking on uneven roads (11 respondents), vibration on steps (7 respondents), and the tendency for the steering wheel to lose control on slopes (5 respondents). This is thought to be due to the lack of space on narrow sidewalks, in particular, which directly affects the difficulty of operation due to road surface conditions.

Many people pointed out “operability”, with issues relating to basic operation such as difficulty in operating the handlebars (10 people), incorrect lever operation (8 people), and difficulty adjusting the dial (7 people). In particular, several people pointed out the phenomenon of confusing lever operation with bicycle brakes, suggesting that previous bicycle riding experience may actually increase the risk of incorrect operation.

Furthermore, in terms of “safety and danger perception”, there was a strong expression of anxiety arising from interactions with the surrounding environment, such as concerns about contact with pedestrians or bicycles (12 people) and concerns about avoiding utility poles and obstacles (9 people). This is thought to be due to a combination of factors including narrow sidewalks and poorly maintained shoulders.

Finally, although a small number of people pointed out social and emotional aspects such as “psychological barriers” and “being concerned about being looked at”, suggesting that the image of electric wheelchairs and the gaze of others may affect willingness to use them.

Table 5  
*Results of Interview Survey After Test Drive Experiment (n = 18)*

Category	Subdivision	Frequency
Operability	Difficulty in steering	10
	Incorrect lever operation	8
	Difficulty adjusting speed with the dial	7
	Difficulty in turning	4
	Need for slowing down rather than sudden acceleration when gripping the lever or sudden stops when releasing the lever	3
Bumps, road surface, vibration	Steering wheel and vehicle body shaking on bumpy roads	11
	Vibration at steps	7
	Easily losing control of steering on slopes	5
Effect of road width	Anxiety on narrow sidewalks	15
	Bicycles and pedestrians travel faster on wide sidewalks than narrow sidewalks	3
Safety and hazard perception	Anxiety about collisions with pedestrians and cyclists	12
	Beware of collisions with utility poles and obstacles	9
	Fear of approaching the road	2
Psychological barriers	Reluctance to use an electric wheelchair	2
	Concerns about being stared at	1
The elderly's perspective	High demands on grip strength and operation for elderly people	5
	Fatigue from long-distance use	2

## Discussion

### Effects of Sidewalk Width on Driving Behavior and Psychology

The results of this study clearly demonstrated that sidewalk width strongly influences the safety, maneuverability, and psychological burden of electric wheelchairs. As shown in Tables 4 and 5, anxiety and perceived difficulty are overwhelmingly greater on narrow sidewalks. This structure, that wider sidewalks have more encounters, but narrower sidewalks have higher psychological burden, is consistent with findings reported in previous research (Kitagawa et al., 1999). At a sidewalk width of 3.25 m, pedestrians are more likely to “avoid or follow” obstacles, whereas narrower sidewalks offer less freedom of behavioral choice, increasing psychological tension even for the same encounter (Kitagawa et al., 1999). In this study, narrow sidewalks further constrict the traversable area due to utility poles, curbs, and sidewalks. This demand on participants to simultaneously look, pay attention, and operate the wheelchair is likely to increase anxiety even when there are only a few people passing by.

The Ministry of Land, Infrastructure, Transport, and Tourism’s minimum sidewalk width of 2.0 m is intended to ensure safe passing (2024). As shown in Table 1, the widths of the sidewalks in this study were 268 cm and 367 cm for the wide sidewalks and 174 cm and 168 cm for the narrow sidewalks, resulting in a difference of approximately 100 cm between the two conditions. Furthermore, the narrow sidewalks were below the 2.0 m standard set by the Ministry of Land, Infrastructure, Transport and Tourism. Consequently, it is inferred that the lack of maneuvering space directly led to increased psychological stress. This study empirically demonstrated that narrow urban sidewalks pose both physical and psychological barriers for power wheelchair users.

### Effects of Steps, Road Surface, and Inclination on Travel Stability

As shown in Table 3, travel speed was significantly lower on the narrow sidewalks (1.16 m/s) compared to 1.36 m/s on the wide sidewalks. On narrow sidewalks, steps, bumps, and inclinations caused the vehicle to sway

or tilt, forcing participants to reduce their speed as they approached the roadway to avoid hitting the protective barrier or falling off the curb onto the roadway. It has been reported that increasing sidewalk gradients and narrowness synergistically increase the difficulty of riding on narrow sidewalks (Tahira & Ueno, 1997), and similar situations were frequently observed on the narrow sidewalks in this study. Table 5 also shows that many participants reported issues such as uneven road surface vibrations (11 participants), vibrations from steps (7 participants), and steering errors on slopes (5 participants). These physical factors likely exacerbated the difficulty of riding and ultimately led to reduced speeds.

Furthermore, the results of this experiment are consistent with previous research findings that asphalt pavement is prone to vibration (Tanaka & Kameno, 2010). On narrow sidewalks, several participants reported experiencing direct physical strain from vibrations. Vibrations not only increase fatigue, pain, and nausea in elderly people, but also hinder fine-tuning of steering. Therefore, the combination of “steps, narrowness, and vibration” is a significant risk factor for electric wheelchairs on narrow urban sidewalks.

### **Factors Causing Operability and Misoperation and Their Background**

Operability issues were related not only to narrow sidewalks but also to the structural and cognitive load of the electric wheelchair. Table 5 shows that the most common issues cited were difficulty in steering (10 participants), incorrect lever operation (8 participants), and difficulty adjusting the dial (7 participants). In particular, multiple errors due to “confusing it with bicycle brakes” were reported. This tendency was more pronounced among participants who were accustomed to riding bicycles on a daily basis. From a cognitive psychology perspective, this is a typical example of “existing schemas inducing malfunctions”.

There are limits to the adaptability expected from mobility devices alone; in reality, “compatibility between infrastructure and mobility” is necessary (Kondo, 2025). The high number of errors reported in this study demonstrates the necessity of not only optimizing mobility device design, but also improving sidewalk environments. Furthermore, even high-performance models like the WHILL (n.d.) are difficult to operate on narrow sidewalks due to the combined effects of steps, slopes, and obstacles. This demonstrates that even high-performance mobility devices cannot completely escape the influence of infrastructure factors, suggesting the need for both sidewalk improvements and vehicle-specific assistive technologies (vibration absorption, directional stability support).

### **Physical Environment and Social Factors Affecting Safety**

An important implication of Tables 4 and 5 is that the psychological burden of electric wheelchair users is strongly influenced not only by “physical narrowness” but also by “social factors” and “interactions with others”. Electric wheelchairs still present psychological hurdles, and factors such as “others’ gazes” and “the perception of being weak” reduce their willingness to use them (Horide, 2023). In this study, interviews also revealed numerous reports of anxiety stemming from social pressure, such as “I feel sorry for making pedestrians wait” and “I’m afraid I might bump into someone”. Experiment participants carefully monitored the sidewalk for unevenness, the location of utility poles, and traffic volume. This indicates that using an electric wheelchair requires not only “operation” but also “information processing effort”, which increases psychological burden.

A VR (virtual reality) simulation experiment (Uno, Fujita, Hashimoto, & Ujihara, 2021) revealed that pedestrian anxiety is more strongly influenced by the distance between vehicles than by vehicle type or speed. Anxiety increases sharply when the distance is particularly short, and even at low speeds (15 km/h or less), anxiety increases with distance. Because electric wheelchairs are prone to close proximity to pedestrians and

cyclists in the limited space of sidewalks, it is likely that this proximity causes anxiety for both the user and those around them. In the narrow sidewalk environment of this study, anxiety likely increased as physical distance decreased. The sense of safety associated with using an electric wheelchair can be interpreted as ensuring a sufficient distance and ensuring that the user will not cause inconvenience to others.

### Conclusion

The safety of electric wheelchairs was revealed to be determined by multiple factors, including sidewalk width, steps and road surface, maneuverability, and psychological safety. The experimental results of this study empirically support the need for a “hybrid approach” combining infrastructure and mobility (Kondo, 2025). The results suggest that four points will be important for future urban transport policies and welfare mobility designs: (1) ensuring sidewalk width (especially at least 2.0 m), (2) reducing steps, slopes, and unevenness, (3) driving assistance technology for narrow sidewalks (vibration reduction and directional stability), and (4) providing guidance and information to reduce the psychological burden on users.

### References

- Arai, M. (March 2019). Genuinely useful accessibility information on transportation for wheelchair users. *Social Design Review*, 10, 100-110.
- Fujimoto, M. (2009). An investigation on the minimum clear width for wheelchair passage. *Research bulletin of Otemae Junior College*, 29, 41-52.
- Horide, Y. (February 2023). Utilizing personal mobility for the last mile of transportation for the elderly. *Rehabilitation Engineering*, 38(1), 18-22.
- Kitagawa, H., Okamoto, H., Mihoshi, A., & Matsumoto, N. (1999). The study of service level for sidewalks under considerations of wheel-chair mixing and its width. *Infrastructure Planning Review*, 16, 617-625.
- Kondo, Y. (October 2025). Toward a society where everyone can move: New Proposals for infrastructure and mobility. *IATSS Review*, 50(2), 109-116.
- Ministry of Land, Infrastructure, Transport and Tourism, Road Bureau. (January 2024). Guidelines for the improvement of road mobility. Retrieved from <https://www.mlit.go.jp/road/road/traffic/bf/kijun/pdf/all.pdf> (accessed on May 12, 2025)
- Mizohata, M. (2002). The study of mobility of silver car for elderly and disabled persons. *Proceedings of Infrastructure Planning*. Retrieved from [http://library.jsce.or.jp/jsce/open/00039/200211\\_no26/pdf/161.pdf](http://library.jsce.or.jp/jsce/open/00039/200211_no26/pdf/161.pdf) (accessed on August 10, 2025)
- Sakai, K., & Yasuda, M. (2024). Verification of the operability of short distance mobility vehicles electric wheelchair WHILL through test drive experiments. *Psychology Research*, 14(4), 121-131.
- Sakai, K. (Dec. 2024). Verification of rearward visibility using side mirrors of short-distance mobility vehicles (electric wheelchair standards) WHILL. *Advances in Machine Learning & Artificial Intelligence*, 5(4), 1-7.
- Tahira, H., & Ueno, Y. (1997). Wheelchair walking experiments on the decreasing section of a stepped sidewalk. *Summaries of the Annual Conference of Japan Society for Interior Studies*, 9, 70-71.
- Tanaka, T., & Kamenno, T. (2010). Research on surface roughness of sidewalk pavement with wheelchairs. *Environmental Information Science*, 24, 315-320. CEIS.
- Uno, H., Fujita, R., Hashimoto, S., & Ujihara, T. (Oct. 2021). A study on the pedestrian's fear while the situation of pedestrian and car passing each other at residential street by using VR simulation. *Journal of the City Planning Institute of Japan*, 56(3), 1343-1350.
- WHILL. (n.d.). Retrieved from <https://whill.inc/jp/> (accessed on March 10, 2025)